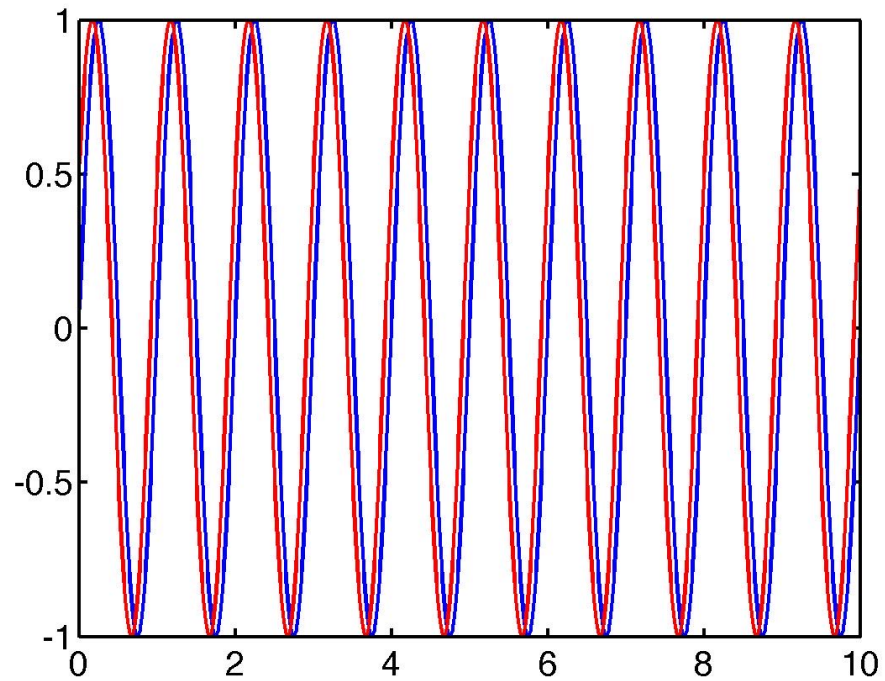
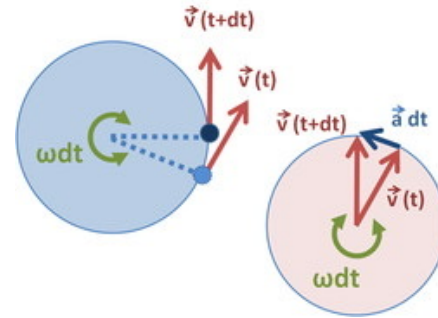


Asking the Right Questions: Random, and Chaotic Motions, Patterns & Networks

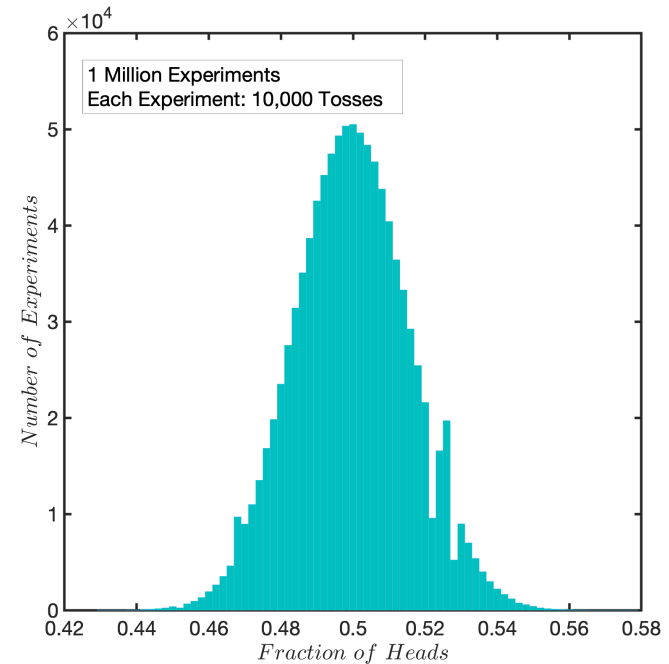
Regular Motion



Planetary Motions



Random Events



Wrong Questions:

- Will the coin toss give heads or tails?
- In 10,000 coin-tosses, what will the 735th toss give?

Right Questions:

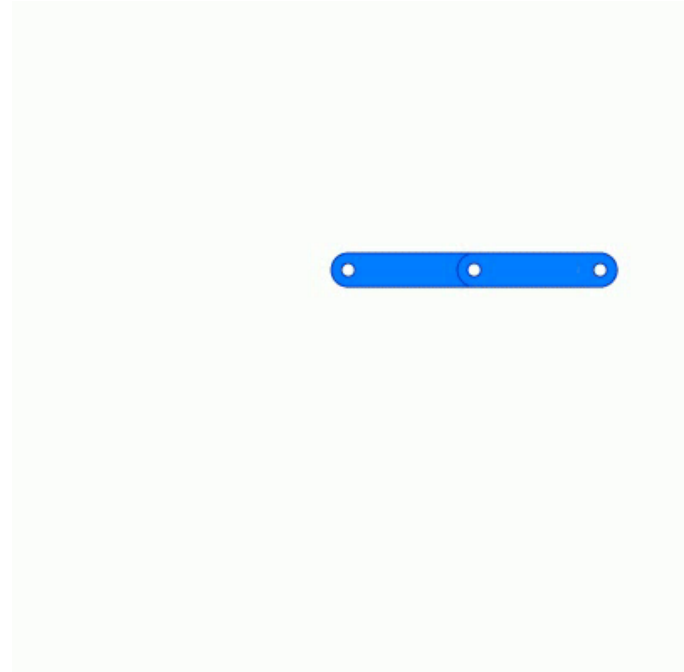
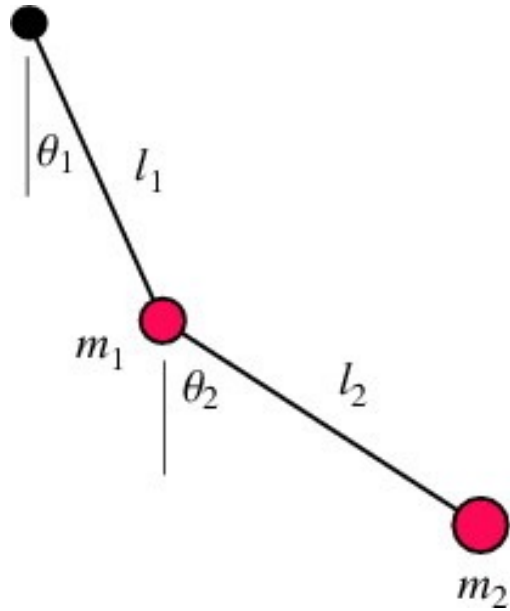
- How many experiments will have a fraction of heads between 0.49 and 0.51.

Chaos



- Deterministic
- Sensitive to the precise start

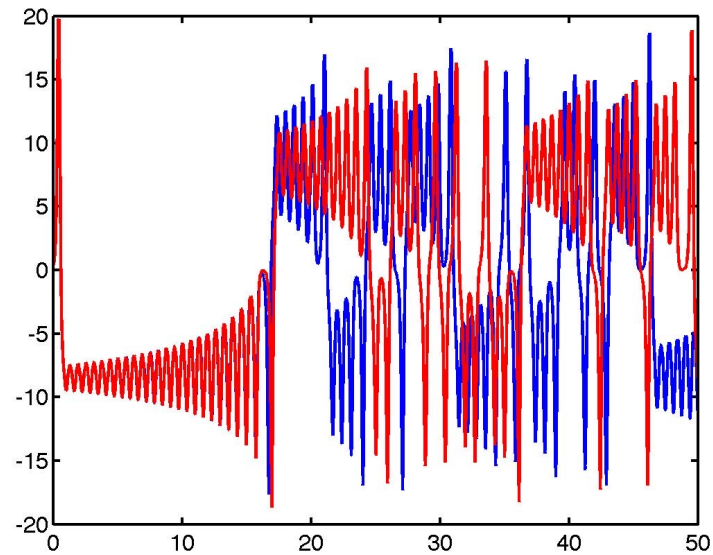
Chaos



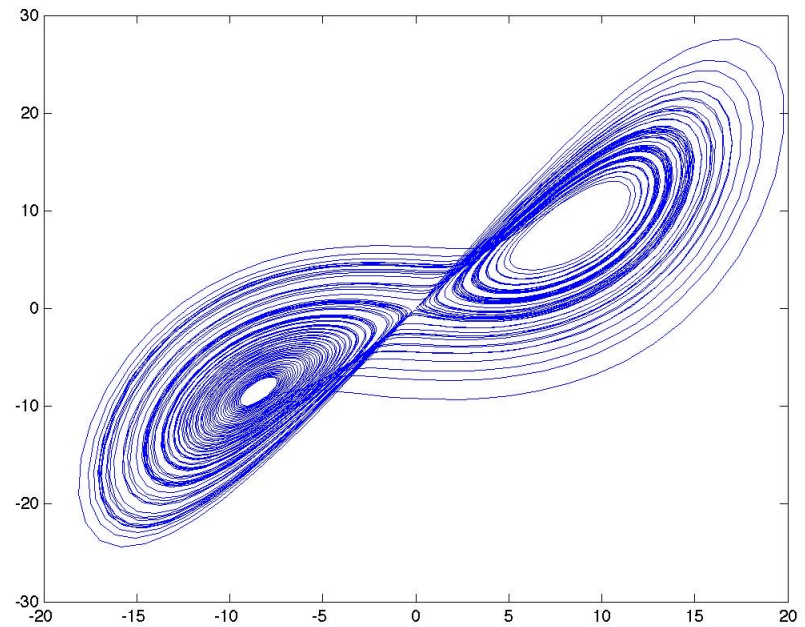
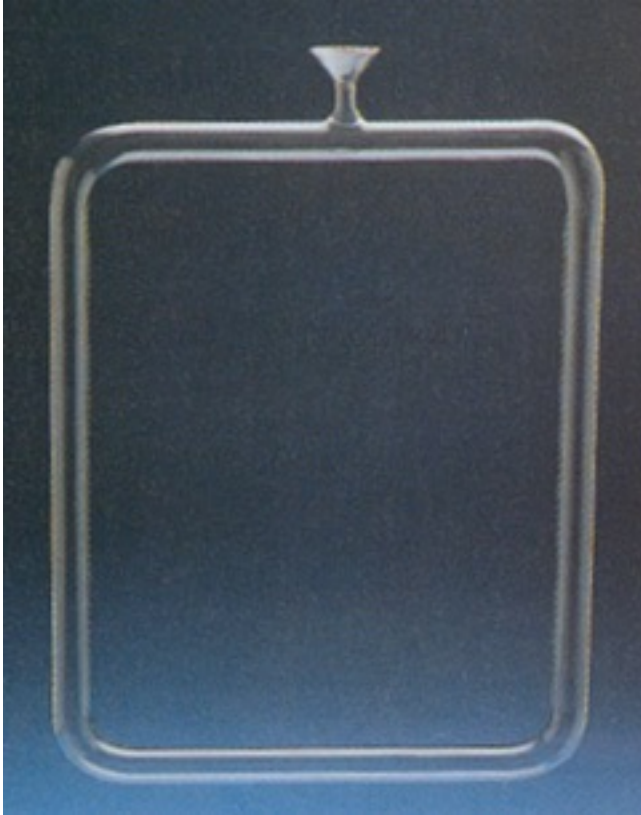
Strange Attractor



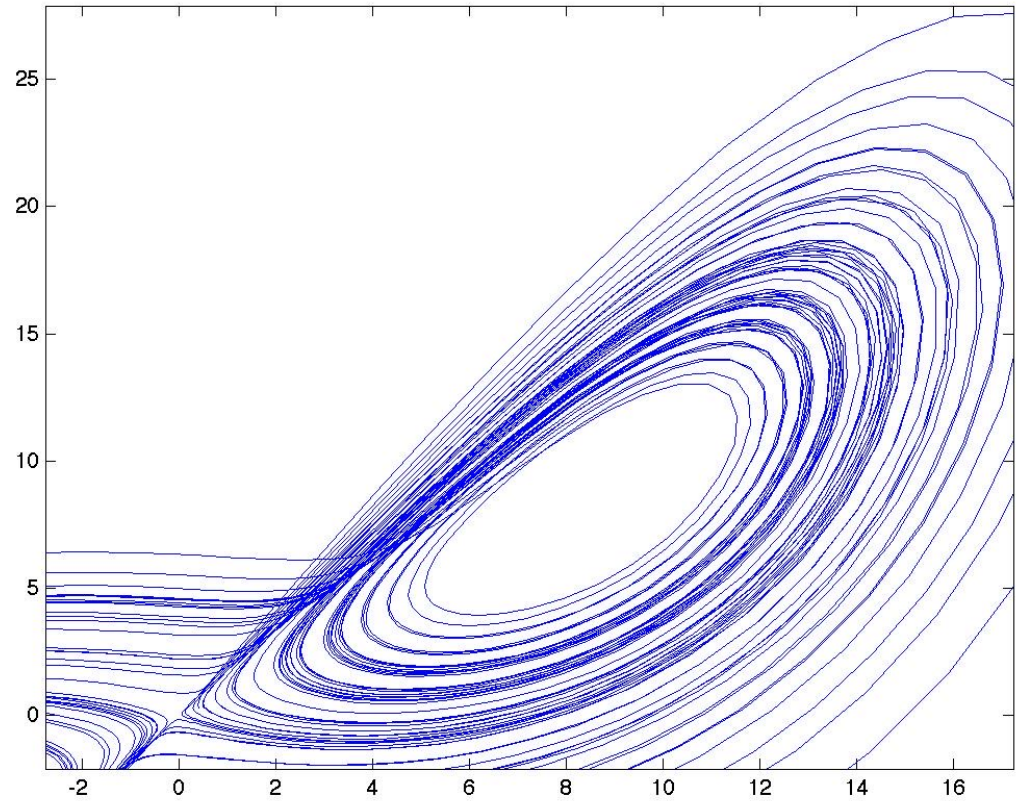
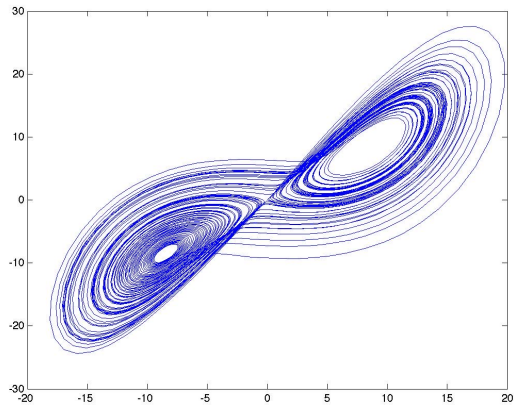
$$\begin{aligned}\frac{dx}{dt} &= \sigma(y - x) \\ \frac{dy}{dt} &= x(\rho - z) - y \\ \frac{dz}{dt} &= xy - \beta z\end{aligned}$$



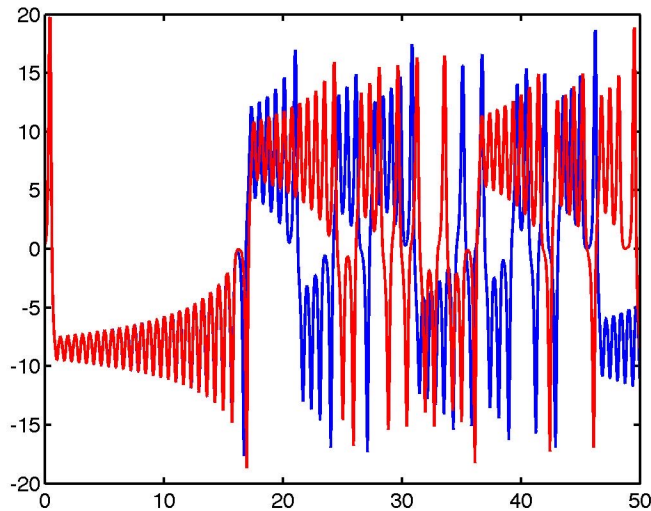
Chaos



Chaos



Chaos: Right and Wrong Questions



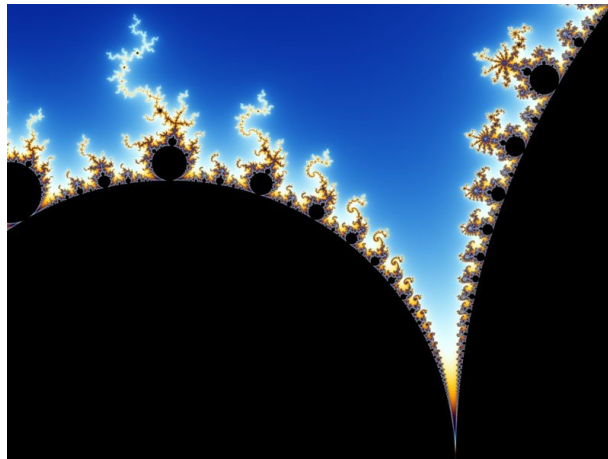
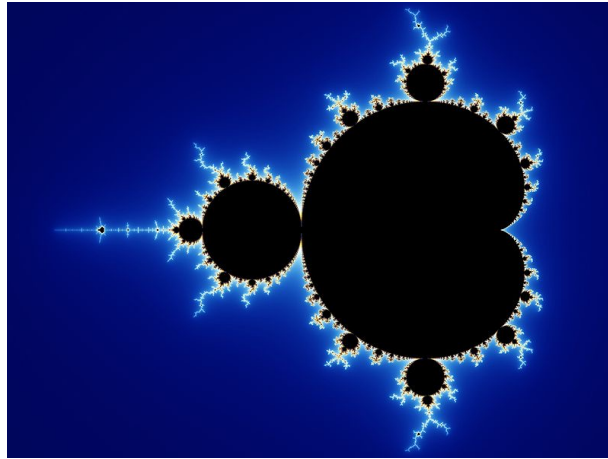
Fractal

Right Questions:

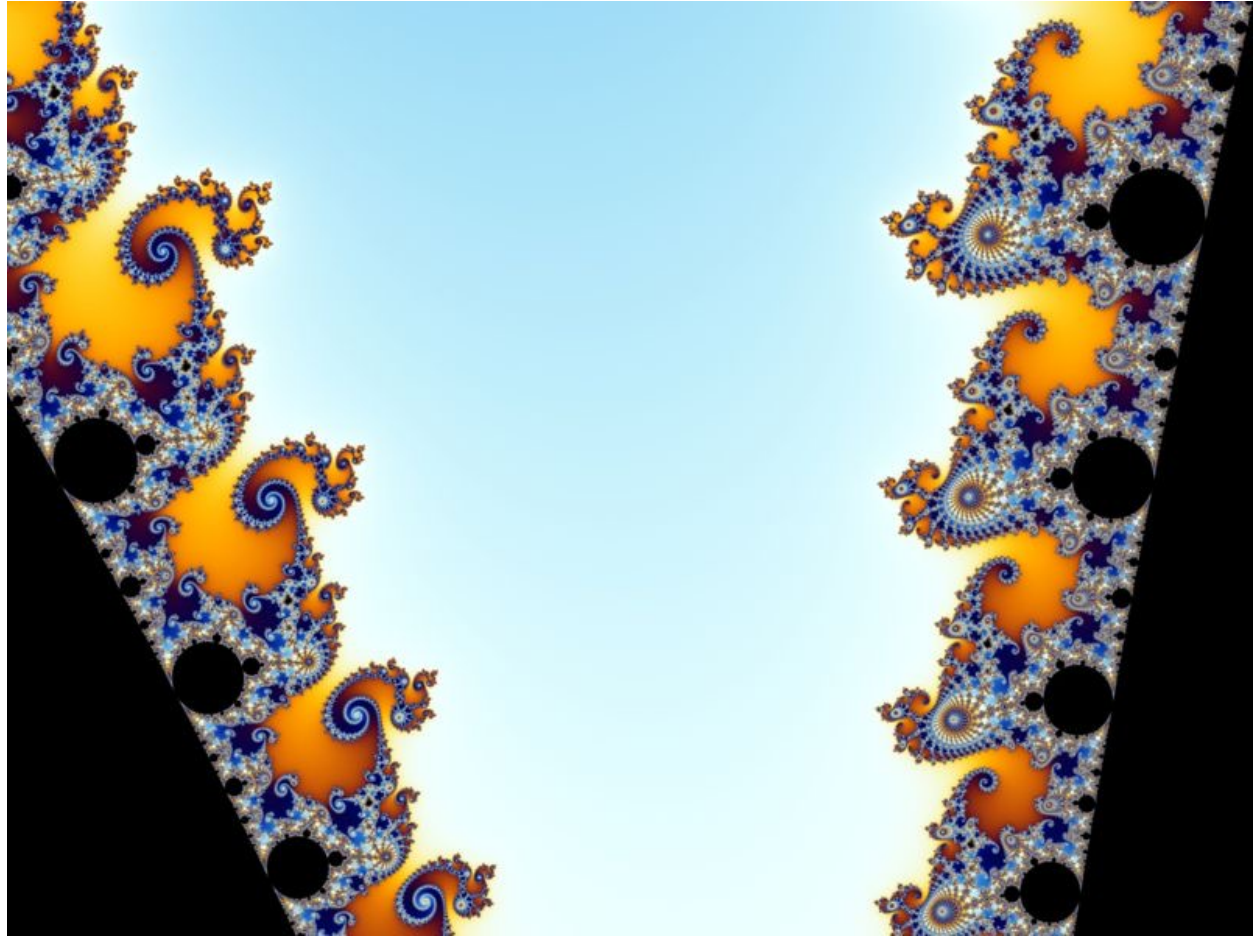
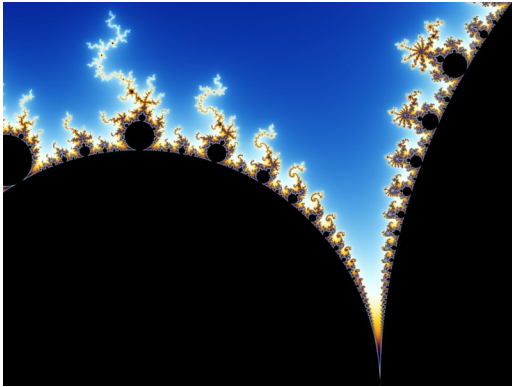
- Properties of the Fractal
- Fractal dimension, expansion rates

Fractals

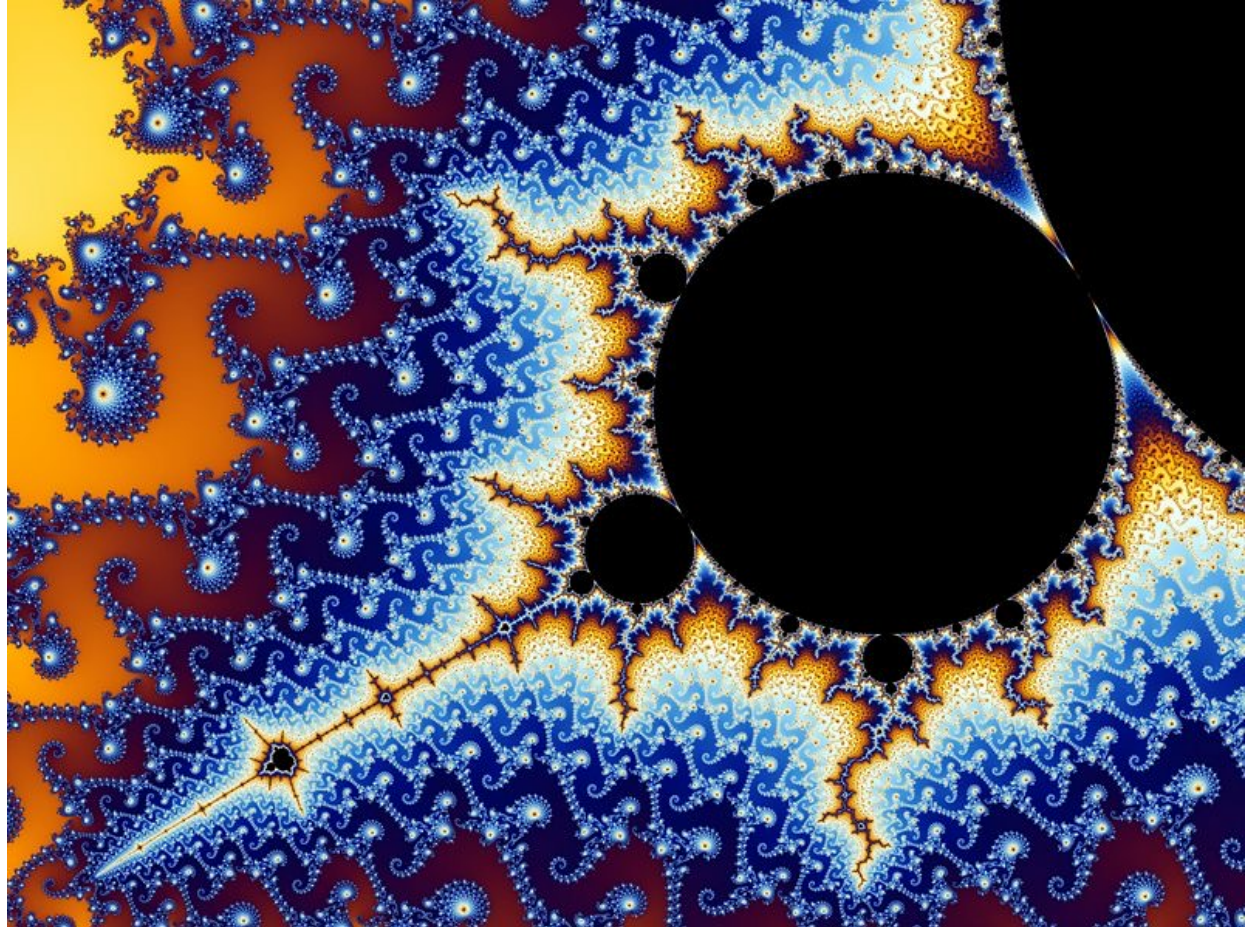
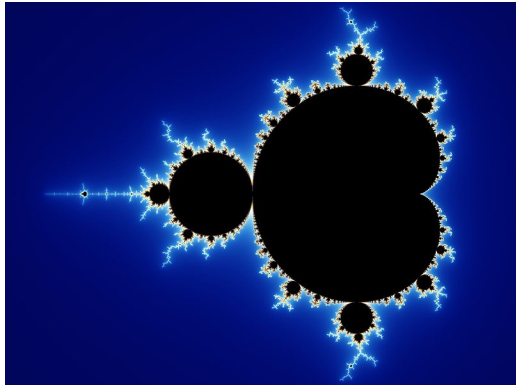
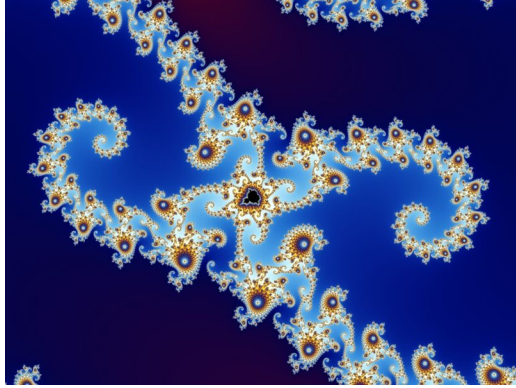
$$z' = z^2 + c$$



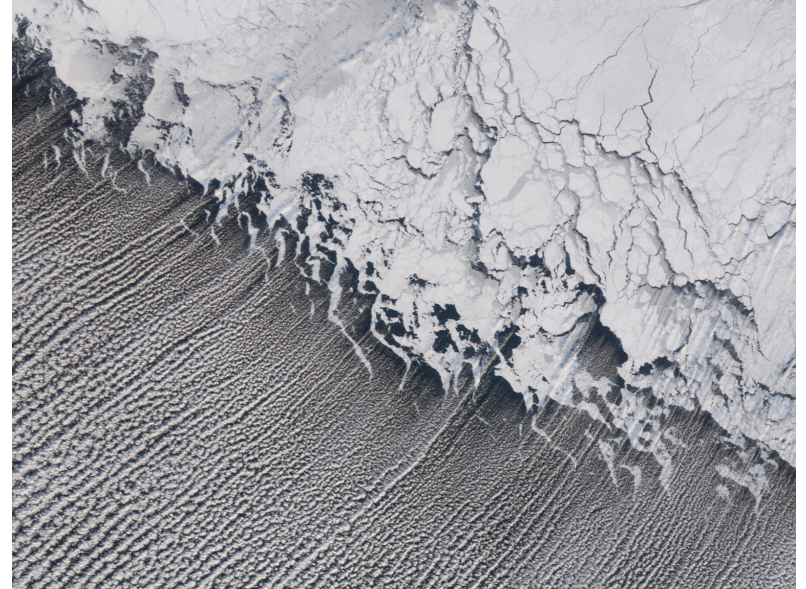
Fractals



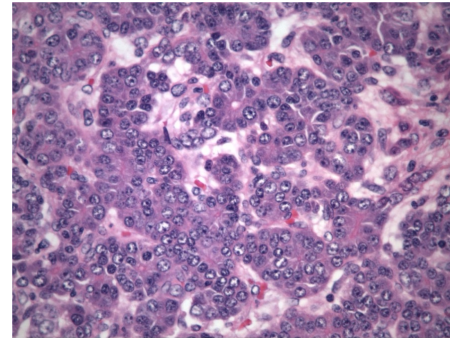
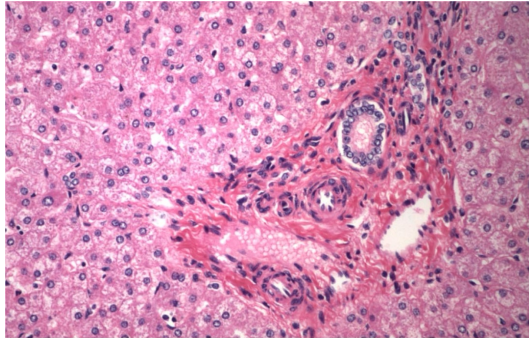
Fractals



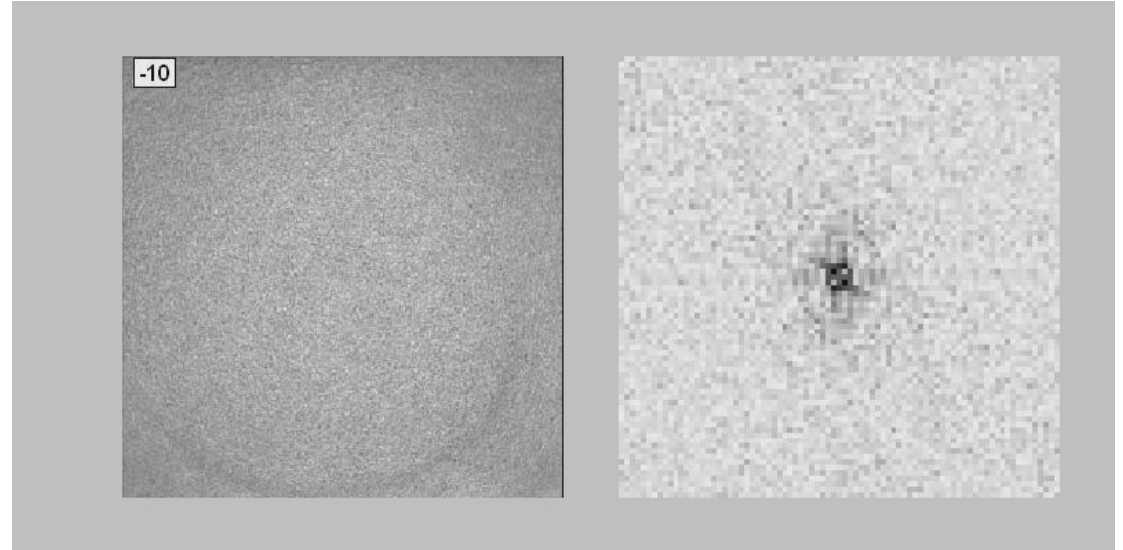
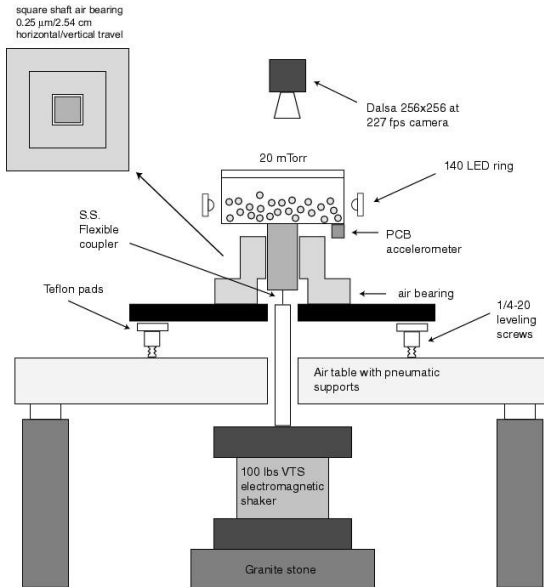
Patterns



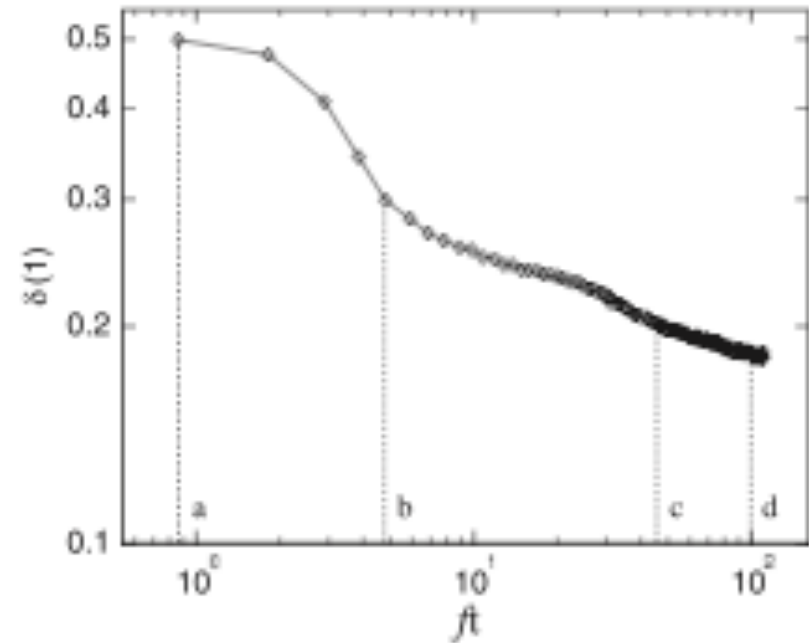
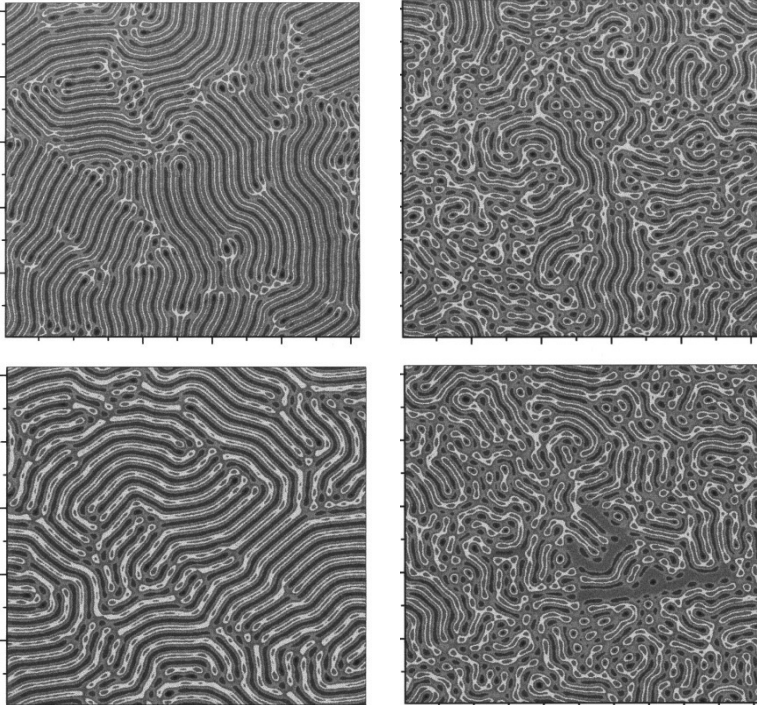
Patterns



Patterns



Patterns

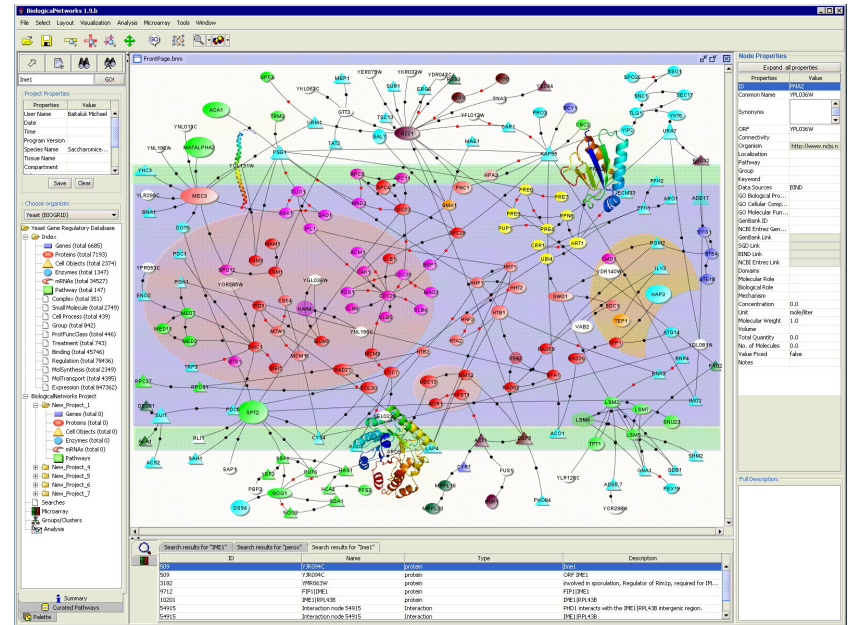


Wrong Questions:

- Pattern details
- Direction of final squares

Right Questions:

- disorder functions
- Their behavior repeats



Signatures of Imminent Changes



- Identify a signature of a growing fracture by looking at the flow
- Flow has turbulent facets; need to search for robust characteristics

